Note on Stimulated Decay of Negative Mesons

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Theories in which the decay of negative mesons is accelerated by electrostatic fields are investigated. Such theories always give radiative decay for free mesons. The competition of radiationless decay of negative mesons increases with Z^5, and the two rates become equal for a value of Z, which depends somewhat on the choice of coupling, but which, for one simple form, is 12. Experimental evidence probably disproves theories of this kind.

VALLEY and Rossi[1] have reported their studies of the decay of mesons in aluminum. They find that the lifetime of negative mesons in that material is about $\frac{1}{3}$ that of positive mesons. They also refer to the suggestion* that the shortened lifetime may be interpreted, not in terms of competing nuclear capture of mesons, but by the acceleration of the decay process itself, presumably because of the strong electric fields acting on negative mesons when they are bound in atomic states. If this were true, we should clearly have a natural interpretation of the regular and marked decrease of observed delayed coincidences from negative mesons as the effective intensity of the electric field increases with atomic number.

One general feature of any theory which provides for appreciable acceleration of meson decay by electric fields needs first to be noted. In effect, even in the absence of matter, fluctuating electric fields, ascribable to the vacuum fluctuations, will always be present. These will in turn lead to stimulated decay accompanied by the emission of light quanta. Thus, in all theories of this kind, the decay of mesons in free space must, at least frequently, be accompanied by γ-ray emission. When negative mesons are trapped in matter, the electrostatic fields of the nuclei compete with the fluctuation fields, giving rise to processes in which no quanta are emitted, and whose probability may be expected to increase markedly with atomic number.

We wish to report briefly some typical calculations bearing on this point. However, we need to note, in a preliminary way, that the evidence[2] as it stands is probably not compatible with the view that normal meson decay involves light quantum emission. It need hardly be pointed out that the results of Anderson[3] and his collaborators in which a decay positron has an observed energy of 25 Mev *could* readily be explained in these terms.

For the calculations we have assumed that the spin of the meson is 0 (it cannot be greater than $\frac{1}{2}$); it then does not affect these results whether the meson field is scalar or pseudoscalar.

One might at first take, as a simple interaction which promises to account for a stimulated decay, the coupling

$$g\varphi_n{}^+\gamma^\mu\varphi_e\partial_\mu U + \text{complex conjugate}, \qquad \text{(A)}$$

where φ_n, φ_e, and U are the neutrino, electron, and meson wave functions and $\partial_\mu = (\partial/\partial x_\mu) - (ie/\hbar c)A_\mu$. As is well known, the free disintegration of a meson into electron and neutrino is highly forbidden with this coupling, and one might suppose that electromagnetic fields would circumvent the selection rule. That this is not true follows from the remark of Nelson,[4] that, in fact, the coupling (A) is for these purposes equivalent to the scalar coupling

$$g(m/\mu)\varphi_n{}^+\varphi_e U, \qquad \text{(A')}$$

(with m the electron, μ the meson, masses) except for terms of higher order in g, which do not enter here. Estimates based on these couplings indicate that the decay rate in aluminum

[1] G. Valley and B. Rossi, Phys. Rev. **73**, 177 (1948).
* These questions were discussed at the Ram Island Conference sponsored by the National Academy of Sciences, June, 1947.

[2] For example, R. D. Sard, and E. J. Althaus (to be published).
[3] Anderson, Adams, Lloyd, and Rau, Phys. Rev. **72**, 724 (1947).
[4] E. C. Nelson, Phys. Rev. **60**, 830 (1941).

is not changed by more than 1 percent from the rate for free mesons.

We have, therefore, examined more complex coupling schemes, such as are obtained by adding to the Lagrangian one of the four following forms

$$gF_{\mu\nu}\varphi_n{}^+\gamma^\mu\gamma^\nu\varphi_e U, \tag{B}$$

$$gF_\mu{}^\nu\varphi_n{}^+\gamma^\mu\varphi_e\partial_\nu U, \tag{C}$$

$$gF_\mu{}^\nu U\partial_\nu(\varphi_n{}^+\gamma^\mu\varphi_e), \tag{D}$$

$$gF_\mu{}^\nu U\varphi_n{}^+\gamma^\mu\partial_\nu\varphi_e. \tag{E}$$

Of these, we have examined only (B) and (C) in detail. The result of the calculation can be expressed in terms of the ratio λ_s/λ_f where λ_f is the rate of ternary free decay, and λ_s is the rate of binary stimulated decay for a negative meson trapped in its atomic K-shell. These ratios are completely fixed by the coupling, and of course independent of the value of g. The results are

$$\lambda_s/\lambda_f=(256/3)(e^2/\hbar c)^4Z^5 \text{ for (B)},$$
$$=1280(e^2/\hbar c)^4Z^5 \text{ for (C)}.$$

The general character of these results can be understood by a simple argument. The vacuum fluctuations leading to the emission of quanta of energy $\sim\mu c^2$ can be characterized by an electric field of the order

$$E_f=(\hbar c)^{\frac{1}{2}}/(\hbar/\mu c)^2.$$

On the other hand, the electric field acting on a meson in the K-shell is

$$E_k=Ze/[(\hbar/\mu c)(\hbar c/e^2)Z^{-1}]^2.$$

Hence, for the ratio of the two rates

$$(E_k/E_f)^2=Z^6(e^2/\hbar c)^5. \tag{1}$$

Detailed calculation shows, however, that in these high energy disintegrations the effective distance of the meson from the nucleus is

$$(\hbar/\mu c)(Ze^2/\hbar c)^{-\frac{3}{4}}$$

rather than the K-radius

$$(\hbar/\mu c)(Ze^2/\hbar c)^{-1},$$

as assumed above. This alters the ratio (1) to

$$Z^5(e^2/\hbar c)^4. \tag{2}$$

We can compare these results with the findings of Valley and Rossi by asking for what value of Z we get a λ_s twice the value of λ_f. Valley and Rossi find $Z\sim 13$; (B) gives $Z=24$; (C) gives $Z=14$. This latter result would clearly be consistent with experiment. Because of the unlikelihood that the basic mechanisms here proposed are realized in nature, we have not examined the cases (D) and (E) in detail.

It is, of course, conceivable that the acceleration of decay would have to be ascribed, not to the electric fields of nuclei, but to the charge density itself. In this case, free decay would not involve γ-ray emission, though it would involve pair emission. It has not seemed profitable to explore these complex alternatives.